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Test Procedure for Gamma Emitters in Drinking Water: Interlaboratory Collaborative Study

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TEST PROCEDURE FOR GAMMA EMITTERS IN DRINKING WATER: Interlaboratory Collaborative Study

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16. ABSTRACT

An interlaboratory collaborative study was conducted to test a procedure for the measurement of gamma emitters in drinking water. Thirty-two laboratories participated in the study. Four reference water samples containing three or all four of the gamma emitters, cobalt-60, ruthenium-106, cesium-134 and cesium-137, at concentrations ranging from 6 to 400 pCi/l, were analyzed in the study.

Except ruthenium-106, the test procedure was shown to provide adequate sensitivity of measurement for the radionuclides analyzed, as required by the National Interim Primary Drinking Water Regulations (NIPDWR), without preconcentration of the radionuclides from the samples.

The average accuracy indexes for cobalt-60, cesium-134 and cesium-137 were 107, 94.9, and 101.6 percent, respectively. For ruthenium at the 60.5 pCi/l concentration (two times the maximum contaminant level), the accuracy index was 100.7 percent.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

ASTM	-- The American Society for Testing and Materials
B	-- beta decay
c/m	-- counts per minute
d/m	-- disintegrations per minute
DOE	-- The Department of Energy
EPA	-- Environmental Protection Agency
Ge(Li)	-- lithium-drifted germanium detector
IAG	-- Interagency Agreement
MCL	-- maximum contaminant level
NaI(Tl)	-- Thallium-activated sodium iodide detector
NIPDWR	-- National Interim Primary Drinking Water Regulations
pCi/l	-- picocuries per liter
pCi/ml	-- picocuries per milliliter
2S%	-- Two sigma percent (two standard deviations in percent)

SYMBOLS

$A_j\%$	-- the accuracy index for the sample j level of gamma emitter concentration
I_{rj}	-- the repeatability interval for sample j level
I_{Rj}	-- the reproducibility interval for sample j level
n	-- the number of replicate analyses
P	-- the number of participants in the collaborative study
S_{ij}	-- the standard deviation of the replicate test results for sample j by Lab i
S_{Lj}	-- the standard deviation of between-laboratories precision for sample j
S_{rj}	-- the repeatability (within-laboratory) standard deviation for the sample j
$\overline{S}_{rj}$	-- the smoothed repeatability standard deviation for sample j
S_{Rj}	-- the reproducibility (combined within- and between-laboratory) standard deviation for sample j
Su	-- the standard deviation reported by the laboratories for each determination
S_{Xj}	-- the standard deviation of the grand average for sample j
t_c	-- the critical value of the bias test for P participants

SYMBOLS (Continued)

t_j	-- the bias value for sample j
T_n	-- the T-test value of the nth replicate, outlier test
$V_{Lj}\%$	-- the coefficient of variation for between-laboratories precision for sample j
V_{rj}	-- the coefficient of variation for repeatability (within-laboratory) for sample j
$V_{Rj}\%$	-- the coefficient of variation for reproducibility (combined within- and between-laboratory) for sample j
X_{ij}	-- the arithmetic average of all replicte test results of sample j by Lab i
X_{ijh}	-- the test result of replicate h of sample j by Lab i
X_j	-- the grand average value for sample j
Y_j	-- the known value of the sample j concentration (pCi/l)

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INTRODUCTION

In accordance with the provisions of the Safe Drinking Water Act, the National Interim Primary Drinking Water Regulations (NIPDWR) were established and regulations for radioactivity i. drinking water became effective June 24, 1977. Maximum contaminant levels for manmade radionuclides in drinking water were defined as that concentration which will produce an annual dose equivalent of 4 mrem/yr at an ingestion rate of 2 liters/day. If several radionuclides are present, the sum of their annual dose must not exceed 4 mrem/yr.

The present work describes an interlaboratory collaborative study of a method selected by the U.S. Environmental Protection Agency (EPA) for the analysis of gamma emitting radionuclides in drinking water. EPA Method 901.1, entitled "Gamma Emitting Radionuclides in Drinking Water" in the EPA procedures manual, EPA-600/4-80-032, was chosen for the study. This method consists of gamma counting a standard water sample of known radionuclide activity in a standard geometry in order to calculate the detector efficiencies for the radionuclides of interest. Subsequently, a homogeneous aliquot of drinking water in the identical geometry is counted, and the gamma emitter concentrations are determined from the known efficiencies.

The purpose of the study was to evaluate the average precision and accuracy of the method under many different laboratory conditions and at concentrations from two times to one tenth of the maximum contaminant levels. Laboratory conditions varied with respect to the detectors (germanium or sodium iodide), standards, spectral stripping methods, sample sizes, and counting times. For the method to be in compliance with the NIPDWR, the detection limits for the gamma emitter being measured must be equal to or less than one tenth of the applicable maximum contaminant level.

CONCLUSIONS

The repeatability precision (within-laboratory precision), reproducibility precision (the combined within- and between-laboratory precision), and the accuracy have been determined for the test procedure by a multilaboratory test with four radionuclides in this study.

The estimated repeatability (within-laboratory), single-operator, single machine, relative precision of the test procedure was evaluated for the determination of cobalt-60, ruthenium-106, cesium-134 and cesium-137. At the maximum contaminant levels for cobalt-60 (100 pCi/l), ruthenium-106 (30 pCi/l), cesium-134 (80 pCi/l), and cesium-137 (200 pCi/l), the respective estimated repeatabilities (averaged over 33, 12, 34, and 34 participants, respectively) are ±7.0 pCi/l (7%), ±14.4 pCi/l (48%), ±7.4 pci/l (9.3%), and ±16 pCi/l (8%) at the 95% confidence level. At one tenth of the maximum contaminant levels for cobalt-60 (10 pCi/l), cesium-134 (8 pCi/l) and cesium-137 (20 pCi/l), the respective estimated repeatabilities (averaged over 23, 16, and 30 participants, respectively) are ±2.9 pCi/l (30%), ±4.6 pCi/l (58%), and ±4.4 pCi/l (22%) at the 95% confidence level.

The estimated reproducibility (combined within- and between-laboratory), multioperator (multilaboratory), single-machine, same-day, relative precision of the test procedure was evaluated for the determination of cobalt-60, ruthenium-106, cesium-134, and cesium-137. At the maximum contaminant levels for cobalt-60 (100 pCi/l) ruthenium-106 (30 pCi/l), cesium-134 (80 pCi/l) and cesium 137 (200 pCi/l), the respective estimated reproducibilities (averaged over 33, 12, 34, and 34 participants, respectively) are ±13 pCi/l (13%), ±22 pCi/l (73%), ±20 pCi/l (25%), and ±27 pCi/l (13%) at the 95% confidence level. At one tenth of the maximum contaminant levels for cobalt-60 (10 pCi/l) and cesium-137 (20 pCi/l), the respective estimated reproducibilities (averaged over 23 and 30 participants, respectively) are ±5.4 pCi/l (54%) and ±6.2 (31%) at the 95% confidence level.

On the basis of test error alone, the absolute difference of duplicate test results obtained in the same laboratory will be expected to exceed the repeatability interval only 5% of the time. At the maximum contaminant levels for cobalt-60 (100 pCi/l), ruthenium-106 (30 pCi/l), cesium-134 (80 pCi/l) and cesium-137 (200 pCi/l), the repeatability intervals are 12.5 pCi/l, 15 pCi/l, 15.9 pCi/l, and 18.4 pCi/l, respectively. At one tenth of the maximum contaminant levels for cobalt-60 (10 pCi/l), cesium-134 (8 pCi/l), and cesium-137 (20 pCi/l), the repeatability intervals are 3.8 pCi/l, 5.9 pCi/l and 6.5 pCi/l.

On the basis of test error alone, the absolute difference of duplicate test results obtained in different laboratories will be expected to exceed

the reproducibility interval only 5% of the time. At the maximum contaminant levels for cobalt-60 (100 pCi/l), ruthenium-106 (30 pCi/l), cesium-134 (80 pCi/l) and cesium-137 (200 pCi/l), the reproducibility intervals are 21 pCi/l, 39 pCi/l, 28 pCi/l, and 37 pCi/l, respectively. At one tenth of the maximum contaminant levels for cobalt-60 (10 pCi/l), and cesium-137 (20 pCi/l), the reproducibility intervals are 7.4 pCi/l, and 8.2 pCi/l.

The accuracy of the test procedure for measuring a gamma emitter at a given concentration was expressed in terms of the accuracy index (grand laboratory average/known value) in percent. Accuracy indices (%) for cobalt-60 at concentrations of 201.6 pCi/l, 98.8 pCi/l, and 9.81 pCi/l were 99.9%, 102.2%, and 119.3%, respectively; for ruthenium-106 at concentrations of 60.5 pCi/l, 29.9 pCi/l, and 15.4 pCi/l were 100.7%, 128.1%, and 181.8%, respectively; for cesium-134 at concentrations of 161.0 pCi/l, 79.6 pCi/l, and 7.9 pCi/l were 93.9%, 92.1%, and 98.7%, respectively; and for cesium-137 at concentrations of 393.5 pCi/l, 202.8 pCi/l, 99.5 pCi/l, and 19.9 pCi/l were 98.9%, 99.7%, 100.0%, and 108%, respectively.

Average lower levels of detection (LLD) were estimated for cobalt-60, ruthenium-106, cesium-134, and cesium-137 to be 7.3 pCi/l, 44 pCi/l, 8.3 pCi/l, and 6.9 pCi/l, respectively. These LLD's were based on the laboratory parameters of 10 participants; however, the LLD for each laboratory can be changed by varying the measurement parameters.

The integrity of the reference samples over the period of the study was demonstrated (negligible loss of the trace radionuclides to the reference sample containers) by the fact that participants transferred the reference samples to other containers to analyze the gamma activities, and yet there was good general agreement between the known and the measured concentrations.

Although the failure of the test procedure to show acceptable sensitivity for a 0.1 MCL concentration of ruthenium-106 might have been predicted, such a failure has now been demonstrated by this study and the need for alternate methodology has been indicated.

The study was made restrictive by the limited number of radionuclides used (4). The precision and accuracy for other radionuclides are not indicated by this study. However, acceptability of the methodology is well demonstrated even with the allowance of variations in such parameters as sample volume analyzed, counting times, and data processing techniques. A less restrictive study (by adding a few more radionuclides) would likely have more clearly demonstrated a limitation of NaI(Tl) detectors because of their limited gamma energy resolution as compared to Ge(Li) detectors.

RECOMMENDATIONS

It is recommended that the test procedure used in this study be used to analyze drinking water samples for gamma emitting radionuclides for compliance under the Safe Drinking Water Act.

It is recommended that an applicability test be included in the test procedure that can be used to determine whether or not the test procedure for a given set of conditions of counting time, counting efficiency, and sample volume, can be used to analyze drinking water samples for a selected radionuclide. To provide for an applicability test, the following changes and additions should be made to the test procedure.

Change 1.4 of the "Scope and Application" to read as follows.

1.4 The method is applicable for analyzing water samples that contain radionuclides emitting gamma photons with energies ranging from about 60 to 200 keV. The required sensitivity of measurement for the more hazardous gamma emitters is listed in the National Interim Drinking Water Regulations (NIPDWR), Section 141.25. For a method to be in compliance, the detection limits for photon emitters must be 1/10 of the applicable limit (maximum contaminant level, MCL).

Add 1.5 to the "Scope and Applications", to read as follows.

1.5 The criterion for the application of this test procedure to analyze drinking water samples for a selected radionuclide to comply with the NIPDWR is derived from Equation 4 of Appendix C, using the factor 2 for the 95% confidence factor instead of 1.96, and is given by the following expression.

$$\frac{4 + (16 + 32tB)^{1/2}}{2t \times E \times b \times 2.22 \times V} \leq 0.1 \text{ MCL (pCi/l)}$$

where
- t = counting time in minutes for the sample and the background
- B = background in cpm of photon energy peak in question
- E = photon counting efficiency, cpm/dpm
- b = abundance of photon question, γdpm/dpm
- 2.22 = conversion constant, dpm/pCi
- V = volume of sample analyzed, liters (l)

It is recommended that analysts using this test procedure for the measurement of gamma emitters in drinking water determine counting efficiencies for each radionuclide to be measured, with standard solutions at exactly the same geometry (sample-to-detector geometry) as that at which samples are to be counted. This will provide accurate counting efficiencies and cancel summing effects. If counting efficiency is read from a general efficiency curve, then care should be taken to make a separate correction for summing effects when that is known to occur with particular radionuclides being analyzed.

The present study showed that ruthenium-106 at the 2 MCL concentration can be measured by the test procedure, and the average lower limit of detection was estimated to be 44 pCi/l (1.5 MCL). Therefore an increased sensitivity by a factor of 15 to 20 is needed to meet the required sensitivity (lower detection limit of 3 pCi/l, required by NIPDWR). The low gamma abundance per decay and the relatively low MCL are largely the causes for the inadequate sensitivity of the test procedure for ruthenium-106. However, ruthenium-106 also decays with beta particle emission at a decay abundance of 100 percent. The high beta abundance combined with the considerably higher beta counting efficiency (than for gamma-ray) would provide adequate sensitivity for ruthenium-106. Therefore, a method that provides for the separation of ruthenium-106 from water samples followed by a beta count is recommended.

EXPERIMENTAL PROCEDURES

ANALYTICAL TEST PROCEDURES

The analytical test procedure (EPA Method 901.1) that was tested in this study is given in detail in Appendix B. Method 901.1 consists of counting a standard water sample of known gamma emitters concentrations to determine detector efficiencies, and subsequently, counting a drinking water sample in the identical geometry. Gamma emitter concentrations of the drinking water sample are calculated from the net count rate and detector efficiency (times the gamma-ray abundance) for the photopeak of interest.

COLLABORATIVE TEST PROCEDURES

Preparation of Standard Solutions

Standards for cobalt-60, ruthenium-106, cesium-134, and cesium-137 were obtained from the Quality Assurance Division of the U.S. EPA, Environmental Monitoring Systems Laboratory--Las Vegas. Since only a limited amount of these relatively high activity (2-10 nCi/ml) standards were available, it was necessary to make dilutions of these standards to obtain activities in the range of about 50 to 200 pCi/ml. EPA standards contained 100 micrograms of stable element carrier per gram of solution and 0.1M HCl (1.0M HCl for ruthenium-106) to provide for stability and integrity. The calibration uncertainties for those standards ranged from 1-3 percent. Dilutions were made by weighing the EPA standards and adding a weighed amount of dilute hydrochloric acid to achieve the desired concentration. Dilutions of cobalt-60, cesium-134, and cesium-137 were made with 0.1M HCl, while 1.0M HCl was used for dilution of ruthenium-106. Aliquots (10-30 ml) of the diluted standards were transferred to glass ampoules, which were sealed to prevent evaporation. Errors resulting from dilution of the original EPA standards were estimated to be very small (<0.1%), and were insignificant compared to the errors given on the calibration certificates (1-3%) from the EPA. A table which was sent to the participating laboratories and lists the data on the gamma emitter standards supplied for the collaborative study is given in Appendix F.

Preparation of Reference Drinking Water Samples

Four reference samples to be analyzed in the collaborative study were prepared by adding weighed amounts of the previously prepared diluted standards to weighed amounts of 0.1M HCl. (Distilled deionized water and Reagent Grade 12M HCl was used for preparation of the 0.1M HCl.) Each of these samples was mixed in a 30-gallon (114-liter) polyethylene drum liner

for at least 6 hours using a peristaltic pump, and then left overnight before dispersing into cubitaners for the collaborative study. Previous studies have shown that mixing for at least 4 hours is sufficient time for complete mixing of the samples (Bishop, et al., 1979). Samples were dispensed in either 1-quart or 1-gallon cubitaners, depending upon the size of sample requested by the participating laboratory.

Appropriate amounts of three or all four of the gamma emitters of interest were added to the samples, such that concentrations ranged from one tenth to twice the maximum contaminant levels. Maximum contaminant levels for these radionuclides were: cobalt-60, 100 pCi/l; ruthenium-106, 30 pCi/l; cesium-134, 80 pCi/l; and cesium-137, 200 pCi/l.

General Procedures

Four reference samples, a copy of EPA Method 901.1 "Gamma Emitting Radionuclides in Drinking Water," calibrated standards of the gamma emitters to be measured, and a set of collaborative study instructions were sent to 38 laboratories. Results from 32 laboratories using EPA Method 901.1 were received, while one other laboratory submitted results but did not use this method. A list of these laboratories is given in Appendix A.

Results from each laboratory were reported on two data sheets (Appendix G). On the first data sheet, the laboratories were requested to list the gamma-rays measured, the counts and standard deviation for each gamma peak, the calculated concentration and standard deviations for each gamma peak, and the count time for each determination of the four reference samples. The second data sheet listed the same information for the standards and background determinations, and also provided the following: volume of sample analyzed, volume of standard analyzed, detector type, standards used, and spectral stripping method. All laboratories were requested to calculate concentrations as of January 1, 1981. In a few instances, the laboratories did not correct their activities to this date and small corrections of the data were made at Mound with the approval of the participating laboratories.

One of the laboratories used Amersham standards and computer analysis of the gamma spectra for a first set of measurements and Mound standards and hand calculation of the gamma spectra for a second set of measurements. Another laboratory made one set of measurements with a Ge(Li) detector and a second set with a NaI(Tl) detector. Here, each set of results from these two laboratories was treated separately rather than using average laboratory results.

Several of the participating laboratories made comments about the study, and a list of pertinent comments is included in Appendix D.

DATA PROCESSING PROCEDURES

Based on the definition of sensitivity (detection limit) in the NIPDWR (1.96σ), laboratory measurements which were reported with standard deviations greater than 50% of the measured value were not used in the data analysis.

Since the uncertainties for these data were so large, the reported data were listed as "less than" values.

Outliers were rejected on the basis of an ASTM-recommended criterion (ASTM, E-178, 1981). For this rejection criterion, with n observations listed in order of increasing magnitude by $x_1 \leq x\,2 \leq x\,3 \leq \ldots \leq x_n$, if the outlying values x_n or x_i are in question, then T_n or T_1 were calculated as follows:

$$T_n = (x_n - \bar{x})/s$$

$$T_1 = (\bar{x} - x_1)/s$$

where: $T_n; T_1$ = test criterion

$\bar{x}$ = arithmetic average of all n values

s = the estimate of the population standard deviation based on the sample data

If T_n or T_1 values exceeded the critical value, the measurement in question was rejected. Critical values of T for a 1 percent two-sided level of significance were used for the rejection criterion.

A statistical evaluation of the test results was carried out by the procedures described in E-691, E-177, and E-178 of the ASTM Standard Part 41, 1981. The standard deviations and other statistical parameters and equations for their calculations are listed below. The standard deviation of individual participant (or laboratory) test results, S_{ij}, was determined by:

$$S_{ij} = \left[\sum_{h=1}^{n_{ij}} (X_{ijh} - \bar{X}_{ij})^2/(n_{ij}-1) \right]^{1/2}$$

where: X_{ijh} = the result reported for the h replicate of the j sample material by Lab i

$\bar{X}_{ij}$ = the mean of the individual results for sample j for Lab i

n_{ij} = the number of replicates reported for sample j by Lab i

The repeatability (within-laboratory) standard deviation, S_{r_j}, for each sample was determined by:

$$S_{r_j} = \left(\frac{(n_{ij}-1)S_{ij}^2 + (n_{2j}-1)S_{2j}^2 + \text{---} (n_{pj}-1)S_{pj}^2}{(n_{ij} + n_{2j} + \text{---} n_{pj}) - P} \right)^{1/2}$$

where: P = number of participants in the study.

The standard deviation of the grand average for each sample, S_x, was determined by:

$$S_{\bar{x}j} = \left[\sum_{i=1}^{P_j} (\bar{X}_{ij} - \bar{X}_j^2/(P-1) \right]^{1/2}$$

where: X_{ij} = the average of the test results for sample material j by Lab i

X_j = the grand average for sample material j

The standard deviation of between-laboratories precision for each sample material, S_{Lj}, was determined by:

$$S_{Lj} = \left(S_{\bar{x}j}^2 - S_{rj}^2/n_{ij} \right)^{1/2}$$

The reproducibility (combined within- and between-laboratory) standard deviation for each sample, S_{Rj}, was determined by:

$$S_{Rj} = \left(S_{rj}^2 + S_{Lj}^2 \right)^{1/2}$$

The coefficient of variation for repeatability (within-laboratory) for each sample, $V_{rj}\%$, was determined by:

$$V_{rj}\% = 100\ S_{rj}/\ \bar{X}_j$$

The coefficient of variation for between-laboratories precision for each sample, $V_{Lj}\%$, was determined by:

$$V_{Lj}\% = 100\ S_{Lj}/\ \bar{X}_j$$

The coefficient of variation for reproducibility (combined within- and between-laboratory) for each sample, $V_{R_j}\%$, was determined by:

$$V_{R_j}\% = 100\ S_{R_j} / \bar{X}_j$$

Smoothed values of the coefficients of variation ($\bar{V}_{rj}$, $\bar{V}_{Lj}$, and $\bar{V}_{rj}$ over the concentration ranges studied were obtained from a log-log fit (regression analysis) of the coefficients or variations versus the concentration level.

Smoothed values of the repeatability and reproducibility standard deviations for each sample, $\bar{S}_{r_j}$ and $\bar{S}_{R_j}$ were determined by the equations:

$$\bar{S}_{rj} = (\bar{V}_{rj}\%)\ \bar{X}_j\ /100$$

$$\bar{S}_{rj} = (\bar{V}_{rj}\%)\ \bar{X}_j\ /100$$

The 95 percent repeatability interval (I_{rj}) and the 95 percent reproducibility interval (I_{Rj}) for each sample were determined using the smooth standard deviations in the equations:

$$I_{rj} = 2(2)^{1/2}\ \bar{S}_{rj} = 2.83\ \bar{S}_{rj}$$

$$I_{Rj} = 2(2)^{1/2}\ \bar{S}_{Rj} = 2.83\ \bar{S}_{Rj}$$

The accuracy index, $A_j\%$, a percent relationship of the grand average, X_j, to the known value, Y_j, for each sample material was determined by:

$$A_j\% = 100\ \bar{X}_j / Y_j$$

A comparison of the grand average value, $\bar{X}_j$, with the known value, Y_j, for each sample in a bias test was determined by the following equation (Youden and Steiner, 1975).

$$t_j = \frac{\bar{X}_j - Y_j}{S_{\bar{X}j}/(P)^{1/2}}, \text{ (P-1) degrees of freedom}$$

where t_j = the bias test result for the j sample

P = the number of participants

RESULTS AND DISCUSSION

Measured gamma emitter concentrations (pCi/l) and standard deviations (Su), calculated by the laboratories for each measurement, are given in Tables 1 through 4 for the four reference samples. The participating laboratories are identified by randomly selected numbers. As stated previously, sets of results from 2 laboratories were considered separately, resulting in a maximum of 34 measured concentrations for each reference sample. Outliers, based on the ASTM test previously discussed, are footnoted in the tables. Based on the definition of sensitivity (detection limit) in the NIPDWR (1.96σ), laboratory measurements which were reported by the laboratories with standard deviations greater than 50% of the measured value are given in Tables 1 through 4 as "less than" values and not used in the data analysis. Reference concentrations, laboratory average concentrations, and standard deviations ($S_{\bar{x}_j}$, S_{y_j}) are also given in Tables 1 through 4.

Tables 5 through 8 give a complete summary of all precision parameters. The known value (Y_j) and the grand average ($\bar{X}_j$) are listed for each sample along with the following precision parameters:

$S_{\bar{x}_j}$, the standard deviation of the grand average for the j sample

S_{r_j}, the pooled standard deviation (within-laboratory) for the j sample

S_{L_j}, the square root of the component of variance between-laboratories, $S^2_{L_j}$, for the j sample

S_{R_j}, an estimate of the overall between-laboratories precision, a combined within- and between-laboratory precision, or reproducibility precision for the j sample

$V_{r_j}\%$, the coefficient of variation for repeatability, or the estimated relative standard deviation for within-laboratory precision, or repeatability index for the j sample

$V_{R_j}\%$, the coefficient of variation for reproducibility, the percent coefficient of variation for the total variability of a single test result including both within- and between-laboratory variability, or reproducibility index for the j sample

$\bar{V}_{r_j}\%$, $\bar{V}_{L_j}\%$, $\bar{V}_{R_j}\%$, smoothed value of $V_{r_j}\%$, $V_{L_j}\%$, or $V_{R_j}\%$

$\bar{S}_{r_j}$, $\bar{S}_{R_j}$, smoothed values of S_{r_j}, S_{R_j}

I_{r_j}, the repeatability interval, the maximum expected difference due to test error between two test results obtained in a single laboratory (or by a single participant) at the j sample level

I_{R_j}, the reproducibility interval, the maximum expected difference due to test error and systematic error between two test results obtained in two different laboratories at the j sample level

A_j%, the accuracy index

t_j, the bias value

t_c, critical value for significance for P participants

Several observations can be made from the precision summaries given in Tables 5 through 8. The laboratory average concentrations ($\bar{X}_j$) agreed very well with the reference concentrations, particularly for cobalt-60 and cesium-137, but some exceptions are evident. By inspecting the accuracy index (A_j, %), and the bias value (t_j) versus the critical value (t_c), a bias in the laboratory average concentration can readily be detected. The ruthenium-106 average concentrations at the maximum contaminant level (MCL) of 30 pCi/l or below this level appear to be biased high. This is shown in Tables 6 and 8, since the accuracy index in each table is considerably greater than 100% and bias value (t_j) in each table is greater than the critical value (t_c). It is obvious that most of the participating laboratories had difficulty measuring ruthenium-106 at such low levels. Only 12 laboratories reported results at the MCL and only 6 laboratories reported results at 50% of the MCL. Several factors may be responsible for the poor precision and accuracy of these ruthenium-106 measurements. The most important factor is evident by inspecting the nuclear data for the gamma emitters of interest given in Table 9. Gamma-ray abundances for ruthenium-106 (20.6% at 511.8 keV and 9.8% at 621.8 keV) are low compared to the abundance of the primary gamma-rays of the other radionuclides measured (>85%). Therefore, less counts are observed for ruthenium-106 and small systematic errors have a larger effect on the measurement. Other factors which might be sources of error are improper or no background substraction and a possible positive bias due to background annihilation radiation (511.0 keV).

It is also evident from Tables 5 and 8 that a negative bias of about 6-8% (A_j = 93.9% and 92.1%) exists for the measurements of cesium-134 at the MCL (80 pCi/l) and at 160 pCi/l. This bias is also shown by the fact that the bias value (t_j) is greater than the critical value (t_c) for cesium in these tables. A bias may not be as evident for cesium-134 measurements in Table 6, because Sample 2 contained only 7.9 pCi/l (approaching the lower level of detection discussed below) and test results were reported by fewer than half of the participating laboratories. In order to ensure that the cesium-134 standards and the cesium-134 concentrations of the reference samples were not in error, they were checked at Mound Facility, EPA-Las Vegas, and Radiological and Environmental Sciences Laboratory, Idaho Falls and found to be in agreement with other cesium-134 results from the eight laboratories which did not use Mound's standards (Amersham and NBS). Also, the average cesium-134 results from the eight laboratories which did not use Mound's

standards were in excellent agreement with the cesium-134 results of the other laboratories which did use Mound's standards. This comparison is shown in Table 10.

If the reference samples were counted in exactly the same geometry as the standards, which were diluted to the appropriate sample size by the participants, gamma-ray summing effects for measurement of cobalt-60 ruthenium-106, and cesium-134 would be cancelled out. However, several laboratories indicated that their efficiencies were obtained from efficiency curves. It would be necessary to make summing corrections of efficiencies obtained from efficiency curves because these samples were counted relatively close to the detector. If these corrections were not made, a negative bias would be observed, as in the case of cesium-134. (In order to estimate the effect of summing on the efficiency for cesium-134, a 0.5-1 water sample containing cesium-134 was counted at Mound using an 80 cm^3 intrinsic germanium detector, and the reduction of the gamma efficiencies due to summing was determined to be about 10%). Summing effects, which would result in a negative bias, were not apparent for ruthenium-106 or cobalt-60, as would be expected. However, the poor precision of the ruthenium-106 measurements would make a relatively small bias difficult to discern. Summation effects for cobalt-60 were obviously compensated for, possibly by using its gamma-ray efficiencies (not corrected for summing) for the efficiency curve measurement.

Based on the values of t_j versus the critical values (t_c) given in Table 7 for cobalt-60 and cesium-137, there appears to be positive bias for these measurements. In both cases the gamma emitter concentration being measured is only one tenth of the maximum contaminant level. At these very low concentrations, positive biases of about 19% ($A_j\%$ = 119 for cobalt-60 and about 8% ($A_j\%$ = 108) for cesium-137 are observed in this study.

Measurement parameters varied greatly for the study, as shown in Table 11. There were 31 germanium and 3 sodium iodide detectors used, 26 sets of results based on Mound standards and 8 sets of results based on other standards, sample sizes from 0.4 to 4.0 l (except one laboratory which used 0.05 l), and counting times from 50 to 4,000 min. Spectral stripping was achieved by computer calculation for 22 sets of results, by hand calculation for 8 sets of results, and by a combination of computer and hand calculation for 4 sets of results.

Table 12 lists the gamma-rays measured by each of the participating laboratories. A spectrum of a sample containing equal concentrations of the four gamma emitters of interest was taken at Mound Facility with an 80 cm^3 germanium detector and is shown in Figure 1. It is obvious in this spectrum that all of the measured gamma-rays listed in Table 12 can be well-resolved with a germanium detector. However, the 512 keV peak of ruthenium-106 will not be resolved from 511 keV annihilation radiation. The resolution for a NaI(Tl) detector would be much poorer and many of these peaks would not be resolved.

Results from the three laboratories (13, 21a, and 24) that used NaI(Tl) detectors are shown in Table 13. Based on this limited data, the average precision and accuracy of these results appear to be comparable to the

results (Tables 1-4) from the other laboratories using Ge(Li) detectors. This indicates that the accuracy of the deconvolution methods used for the NaI(Tl) spectra analysis was comparable to the Ge(Li) spectra analysis for the samples analyzed. However, analysis of the poorly resolved NaI(Tl) spectra would obviously be more complex and labor intensive.

Although the participating laboratories were requested to supply background information (counts and standard deviation), only 10 laboratories reported background results. Lower levels of detection (LLD) were estimated (Paternack and Harley, 1971) for the 10 laboratories and are given in Table 10. Average LLD's for the ten laboratories were: cobalt-60 = 7 pCi/l; ruthenium-106 = 44 pCi/l; cesium-134 = 8 pCi/l; and cesium-137 = 7 pCi/l. It is evident that in all cases except ruthenium-106 the LLD's are equal or less than one-tenth of the applicable maximum contaminant level for cobalt-60 (100 pCi/l), ruthenium-106 (30 pCi/l), cesium-134 (80 pCi/l) and cesium-137 (200 pCi/l).

A fair comparison between the precision and accuracy of test results obtained with Ge(Li) and NaI(Tl) detectors cannot be made from this study because so few of the laboratories used NaI(Tl) detectors. However, Table 13 shows the averages of results for laboratories using Ge(Li) detectors and for laboratories using NaI(Tl) detectors. Test results for both detectors show acceptable sensitivities for cobalt-60, cesium-134, and cesium-137 at the 0.1 MCL. Neither detector shows acceptable sensitivity for 0.1 MCL concentrations of ruthenium-106. At the MCL concentration for ruthenium-106, the Ge(Li) detector, based on an 11 laboratory average, shows a high bias (31%), while the NaI(Tl) detector, based on a single laboratory average, shows a slight negative bias (8%).

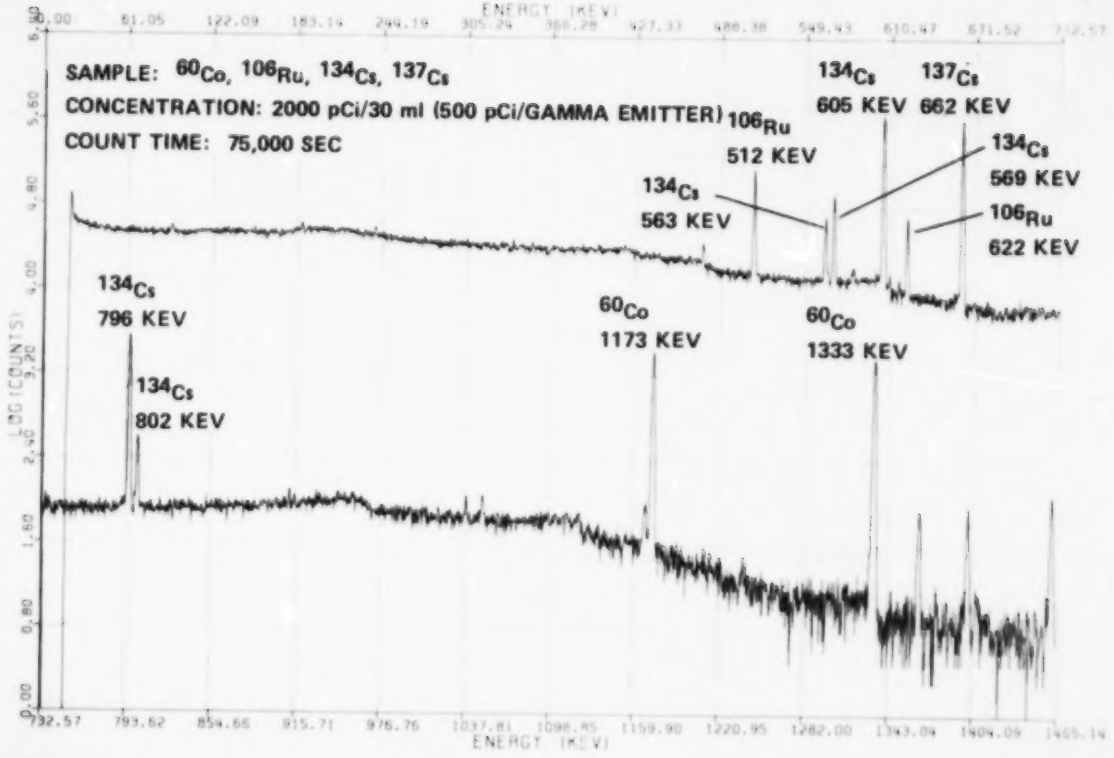

Figure 1. Spectrum of the gamma emitters used in the collaborative study taken with a 80 cm^3 germanium detector.

TABLE 1. GAMMA EMITTERS IN WATER, ANALYSIS DATA FOR SAMPLE 1

Lab [a]	Radionuclide Concentration, pCi/l ± Su			
	Co-60	Ru-106	Cs-134	Cs-137
1A	213 ± 5.3	<63	156 ± 4.5	215 ± 4.5
	199 ± 6.5	<83	147 ± 4.7	211 ± 5.4
	220 ± 6.2	<75	162 ± 6.4	218 ± 5.2
1B	174 ± 5.6	61 ± 20	146 ± 6.4	185 ± 5.0
	181 ± 4.4	52 ± 23	141 ± 2.6	189 ± 4.1
	188 ± 5.2	101 ± 21	143 ± 3.0	183 ± 4.5
2	200 ± 2.5	48 ± 7.7	155 ± 1.9	203 ± 2.2
	199 ± 2.0	45 ± 5.9	159 ± 1.6	204 ± 1.8
3	187 ± 32	<71	170 ± 9.2	205 ± 11.0
	214 ± 17	<69	155 ± 7.1	190 ± 11.0
4	210 ± 6.7	22 ± 8.4	171 ± 4.9	227 ± 6.0
5	200 ± 3.4	80 ± 15	139 ± 3.9	207 ± 4.1
	202 ± 3.3	84 ± 17	148 ± 3.8	208 ± 4.2
6	214 ± 11	70 ± 18	146 ± 9.3	207 ± 10
	206 ± 11	71 ± 15	152 ± 8.7	215 ± 11
	203 ± 11	62 ± 13	132 ± 7.0	203 ± 11
	199 ± 11	63 ± 13	142 ± 8.0	202 ± 10
7	197 ± 16	<73	136 ± 12	191 ± 13
	222 ± 17	<70	163 ± 12	191 ± 13
8	182 ± 15	<180	144 ± 14	203 ± 15
	181 ± 20	<200	148 ± 16	192 ± 16
9	202 ± 7.4	95 ± 14	148 ± 5.1	205 ± 5.9
	193 ± 7.4	79 ± 18	155 ± 5.2	198 ± 5.9
10	193 ± 5.1	-	165 ± 16	204 ± 5.5
	205 ± 4.6	-	157 ± 5.7	198 ± 5.4
11	203 ± 3.8	<62	153 ± 3.7	214 ± 3.1
	209 ± 3.7	<63	146 ± 3.0	211 ± 3.1
12	200 ± 4.1	62 ± 11	143 ± 2.8	207 ± 3.4

(continued)

See footnotes at end of Table, page 18.

TABLE 1. (Continued)

Lab [a]	Radionuclide Concentration, pCi/l ± Su			
	Co-60	Ru-106	Cs-134	Cs-137
13	200 ± 1.1	60 ± 3.7	157 ± 1.2	201 ± 1.1
	201 ± 1.1	55 ± 3.8	156 ± 1.2	203 ± 1.1
14	202 ± 4.7	63 ± 17	151 ± 4.4	217 ± 4.3
	218 ± 4.9	56 ± 18	155 ± 4.7	210 ± 4.4
15	197 ± 5.9	37 ± 12	131 ± 5.0	212 ± 5.0
	193 ± 7.9	<50	145 ± 5.9	214 ± 6.9
16	192 ± 11	-	159 ± 10	205 ± 10
	224 ± 11	-	128 ± 12	219 ± 11
17	193 ± 14	69 ± 19	157 ± 12	195 ± 13
	193 ± 14	76 ± 25	151 ± 11	194 ± 14
18	203 ± 2.8	56 ± 10	149 ± 2.0	209 ± 2.2
	205 ± 2.8	61 ± 10	150 ± 2.0	207 ± 2.1
19	198 ± 4.1	<76	156 ± 3.4	196 ± 4.7
	201 ± 4.1	<74	155 ± 3.5	199 ± 5.0
20	202 ± 10	<90	140 ± 8.0	190 ± 10
	208 ± 19	<40	151 ± 13	196 ± 15
21A	200 ± 10	<135 [c]	160 ± 10	180 ± 6.4
21B	210 ± 25	<160 [c]	170 ± 20	160 ± 20
22	214 ± 11	-	163 ± 10	190 ± 12
	207 ± 11	-	144 ± 10	218 ± 11
23	201 ± 8.0	146 ± 26 [b]	139 ± 4.6	197 ± 7.0
	209 ± 7.0	-	152 ± 4.8	200 ± 6.0
24	195 ± 6.3	57 ± 21	158 ± 6.6	202 ± 6.4
	195 ± 6.3	74 ± 21	155 ± 6.7	210 ± 6.5
25	204 ± 11	<82	114 ± 13	225 ± 10
	231 ± 11	<140	169 ± 12	181 ± 10
26	195 ± 7.1	-	150 ± 13	195 ± 8.9
	195 ± 7.1	-	160 ± 5.7	217 ± 8.7

(continued)

See footnotes at end of Table, page 18.

TABLE 1. (Continued)

Lab [a]	Radionuclide Concentration, pCi/l ± Su			
	Co-60	Ru-106	Cs-134	Cs-137
27	195 ± 6.0	<70	143 ± 5.0	191 ± 4.0
28	206 ± 16	-	118 ± 30	193 ± 24
	193 ± 25	-	119 ± 35	198 ± 24
29	202 ± 3.8	62 ± 12	163 ± 3.2	210 ± 3.1
	197 ± 4.5	46 ± 19	164 ± 3.9	209 ± 3.7
30	233 ± 11	<109	151 ± 6.6	220 ± 8.5
	206 ± 8.7	<99	142 ± 5.7	222 ± 7.3
31	191 ± 17	<149	132 ± 15	195 ± 17
	169 ± 20	<143	144 ± 21	204 ± 20
32	203 ± 4.7	92 ± 28	170 ± 4.3	202 ± 4.5
	205 ± 5.7	46 ± 27	169 ± 10	209 ± 7.2
Lab Ave. $\pm S\bar{X}_j$	201.7 ± 9.2	60.9 ± 16.0	151.2 ± 10.6	202.2 ± 12.1
Ref. Conc. $\pm Sy_j$	201.9 ± 3.1	60.5 ± 1.1	161.0 ± 4.4	202.8 ± 4.7

[a] Less than values were either reported by the laboratories or used if the errors reported were ≤50% of the reported value. A blank means no data was reported by the lab. Also applies to Tables 2-4.
[b] Rejected by ASTM test for outliers.
[c] The 512 keV peak not completely resolved.

TABLE 2. GAMMA EMITTERS IN WATER, ANALYSIS DATA FOR SAMPLE 2

Lab	Radionuclide Concentration, pCi/l ± Su			
	Co-60	Ru-106	Cs-134	Cs-137
1A	114 ± 4.1	<57	<7	437 ± 5.9
	107 ± 5.1	<75	<7	428 ± 7.2
	115 ± 4.8	<72	<9	452 ± 6.8
1B	94 ± 4.2	<51	9.0 ± 1.7	373 ± 6.9
	97 ± 3.4	-	2.9 ± 1.4	370 ± 5.6
	99 ± 3.9	<43	9.5 ± 1.6	377 ± 6.3
2	100 ± 1.8	25 ± 6.8	7.0 ± 0.8	399 ± 2.7
	98 ± 1.3	7.0 ± 5.3	7.0 ± 0.6	398 ± 2.1
3	108 ± 7.1	<59	<19	340 ± 14
	104 ± 8.5	<58	<16	350 ± 14
4	103 ± 4.7	<43	10.0 ± 1.7	414 ± 7.5
5	100 ± 2.4	-	-	402 ± 5.6
	102 ± 2.4	-	8.4 ± 1.6	399 ± 5.2
6	102 ± 6.1	-	6.5 ± 1.5	407 ± 18
	101 ± 6.9	-	8.0 ± 2.1	394 ± 18
7	88 ± 15	<70	<24	371 ± 15
8	75 ± 11 [a]	<160	<27	350 ± 20
9	94 ± 5.2	50 ± 15	6.7 ± 2.6	386 ± 7.9
	98 ± 5.0	53 ± 13	8.2 ± 2.3	396 ± 8.1
10	102 ± 9.2	-	8.3 ± 3.7	396 ± 6.7
	96 ± 7.8	-	-	377 ± 6.8
11	100 ± 3.0	<61	7.7 ± 0.9	402 ± 13.7
	106 ± 3.0	<59	7.9 ± 0.9	409 ± 3.7
12	89 ± 2.7	24 ± 8.4	6.1 ± 0.9	379 ± 4.3
13	99 ± 1.1	20 ± 2.5	6.3 ± 0.7	396 ± 1.4
	99 ± 1.1	18 ± 2.6	8.3 ± 0.7	398 ± 1.4
14	102 ± 3.5	-	-	415 ± 5.4
	104 ± 3.6	-	-	411 ± 5.4

(continued)

See footnotes at end of Table, page 21.

TABLE 2. (Continued)

Lab	Radionuclide Concentration, pCi/l ± Su			
	Co-60	Ru-106	Cs-134	Cs-137
15	96 ± 3.6	<15	<10	403 ± 6.7
	108 ± 10	<15	8.0 ± 2.0	420 ± 20
16	97 ± 8	-	15.7 ± 3.0 [a]	387 ± 13
	95 ± 8	-	-	387 ± 14
17	104 ± 8.0	<33	7.3 ± 1.7	378 ± 23
18	99 ± 1.9	<20	9.1 ± 1.2	407 ± 3.1
19	94 ± 2.9	<65	7.4 ± 1.6	383 ± 6.5
20	95 ± 12	<50	<9	370 ± 19
	108 ± 14	<50	<15	380 ± 20
21A	100 ± 10	-	-	370 ± 10
21B	100 ± 20	-	-	350 ± 30
22	98 ± 11	-	-	385 ± 12
	97 ± 10	-	-	394 ± 11
23	105 ± 4.5	-	-	392 ± 8.0
24	93 ± 5.0	-	-	378 ± 6.8
	92 ± 5.0	-	-	390 ± 6.8
25	99 ± 9.3	<81	<14	407 ± 12
26	102 ± 9.9	-	-	383 ± 11
27	113 ± 5.0	<70	<10	405 ± 7.0
28	115 ± 30	-	-	373 ± 31
29	100 ± 2.9	<38	<6	395 ± 4.3
	96 ± 3.3	<43	<6	387 ± 4.7
30	114 ± 6.4	<67	12 ± 2.9	421 ± 9
	109 ± 18	30 ± 7.9	6.0 ± 0.6	415 ± 2.4
31	101 ± 18	<138	<15	362 ± 17

(continued)

See footnotes at end of Table, page 21.

TABLE 2. (Continued)

Lab	Radionuclide Concentration, pCi/l ± Su			
	Co-60	Ru-106	Cs-134	Cs-137
32	102 ± 2.0	27 ± 12.8	7.5 ± 3.5	403 ± 6.3
Lab Ave. $\pm S\bar{X}_j$	100.9 ± 6.1	28.0 ± 12.8	7.8 ± 1.0	389.3 ± 20.9
Ref. Conc. $\pm Sy_j$	98.8 ± 1.5	15.4 ± 0.3	7.9 ± 0.2	393.5 ± 9.2

[a] Rejected by ASTM test for outliers.

TABLE 3. GAMMA EMITTERS IN WATER, ANALYSIS DATA FOR SAMPLE 3

Lab	Radionuclide Concentration, pCi/l ± Su			
	Co-60	Ru-106	Cs-134	Cs-137
1A	12.9 ± 2.8	<53	<5.4	27 ± 2.2
	17.5 ± 2.7	<64	<6.1	23 ± 2.4
1B	14.7 ± 2.1	<51	-	19 ± 2.2
	15.1 ± 1.7	<59	-	23 ± 1.9
2	8.0 ± 0.9	<23	<3	21 ± 0.9
	11.0 ± 0.6	<14	<1	24 ± 0.6
3	15.5 ± 5.3	<43	<10	20 ± 4.7
	<12	<40	<10	12 ± 3.8
4	23.7 ± 3.3 [a]	<5	-	22 ± 2.9
5	14.0 ± 1.7	-	-	22 ± 1.9
	13.1 ± 1.2	-	<2	22 ± 1.6
6	12.0 ± 1.0	-	-	19 ± 2.0
	11.0 ± 2.0	-	-	20 ± 2.0
7	<26	<130	<16	20 ± 11
8	27 ± 11 [a]	<180	<31	20 ± 10
9	6.4 ± 2.4	<54	<4	22 ± 2.2
	6.9 ± 2.1	<45	<7	20 ± 2.2
10	11 ± 2.3	-	-	18 ± 2.3
	10 ± 2.5	-	-	21 ± 2.5
11	11.0 ± 2.4	<55	<7.0	18 ± 2.0
	8.0 ± 2.3	<54	<6.3	18 ± 2.0
12	8.3 ± 1.1	<11	<1	21 ± 1.3
13	8.5 ± 0.7	<10	<3	22 ± 0.8
	10.8 ± 0.7	<15	<3	19 ± 0.8
14	11.0 ± 1.7	-	-	25 ± 2.1
15	<10	<15	9 ± 3	25 ± 4.7
	<10	<15	<10	23 ± 3.0
16	9.7 ± 2.3	-	-	20 ± 4.1
	9.7 ± 4.8	-	-	23 ± 3.5

See footnotes at end of Table, page 23.

(continued)

TABLE 3. (Continued)

Lab	Radionuclide Concentration, pCi/l ± Su			
	Co-60	Ru-106	Cs-134	Cs-137
17	12.1 ± 1.8	<19	<3	20 ± 2.2
18	12.7 ± 1.1	<20	<5	19 ± 1.2
19	9.7 ± 1.2	<45	<4.6	22 ± 2.5
	10.3 ± 1.2	<46	<4.7	21 ± 2.3
20	<14	<40	<4	19 ± 6.0
	<15	<40	<4	16 ± 5.0
21A	16.0 ± 6.0	-	-	23 ± 10
21B	<60	-	-	<37
22	-	-	-	30 ± 7.5
23	-	-	-	19 ± 4.0
24	-	-	-	21 ± 3.8
	10.8 ± 3.8	-	-	20 ± 3.8
25	<10	<76	<13	35 ± 7.5 [a]
26	10.4 ± 2.8	<22	-	21 ± 4.2
27	13.8 ± 2.2	<40	<10	24 ± 1.8
28	-	-	-	-
29	9.8 ± 0.8	<16	<2	18 ± 0.7
	10.8 ± 1.2	<26	<3	19 ± 1.3
30	<7	<49	<5	<20
	13.8 ± 1.6	<28	<3	22 ± 1.9
31	<40	<129	<12	<15
32	13.5 ± 2.1	<35	<3	25 ± 1.8
Lab Ave. $\pm S\bar{X}_j$	11.7 ± 2.5	<45	<7	21.5 ± 2.7
Ref. Conc. $\pm S_{Y_j}$	9.81 ± 0.15	5.9 ± 0.1	-	19.9 ± 0.5

[a] Rejected by ASTM test for outliers.

TABLE 4. GAMMA EMITTERS IN WATER, ANALYSIS DATA FOR SAMPLE 4

Lab	Radionuclide Concentration, pCi/l ± Su			
	Co-60	Ru-106	Cs-134	Cs-137
1A	<7	<52	84 ± 3.7	103 ± 3.2
	<8	<71	73 ± 3.6	111 ± 4.1
1B	<6	<51	72 ± 2.4	96 ± 3.7
	<8	<59	73 ± 1.9	85 ± 2.9
2	<3	<18	76 ± 1.8	102 ± 2.0
	<3	30 ± 4.2	75 ± 1.0	99 ± 1.1
3	<7	<46	66 ± 17	93 ± 8.1
4	<14	<22	82 ± 3.4	106 ± 4.1
5	-	-	85 ± 3.5	102 ± 2.8
	<2	-	78 ± 3.6	107 ± 2.9
6	-	28 ± 10	74 ± 5.7	106 ± 5.5
	-	29 ± 11	69 ± 4.3	101 ± 4.3
7	<26	<130	70 ± 9.5	83 ± 12
8	<36	<200	78 ± 13	93 ± 12
9	<4	41 ± 14	72 ± 3.7	92 ± 4.1
	<4	54 ± 14	69 ± 3.6	101 ± 4.1
10	-	-	79 ± 2.5	104 ± 3.8
	-	-	80 ± 2.5	104 ± 3.9
11	<7	<59	91 ± 22	295 ± 3.3 [a]
12	<2	36 ± 8.3	74 ± 2.1	101 ± 2.6
13	<2	20 ± 2.5	80 ± 0.8	104 ± 1.1
	<2	35 ± 2.5	82 ± 0.8	100 ± 1.1
14	-	-	79 ± 3.2	110 ± 3.4
15	<10	40 ± 18	75 ± 9.5	106 ± 6.4
	<10	42 ± 20	65 ± 2.0	107 ± 1.5
16	-	-	71 ± 6.2	103 ± 7.3
	-	-	68 ± 7.2	112 ± 6.9
17	<3	36 ± 10	72 ± 5.9	92 ± 6.9

(continued)

See footnotes at end of Table, page 25.

TABLE 4. (Continued)

Lab	Radionuclide Concentration, pCi/l ± Su			
	Co-60	Ru-106	Cs-134	Cs-137
18	<10	57 ± 9.0	66 ± 1.3	93 ± 1.4
19	<5	<54	79 ± 2.5	93 ± 3.5
20	<2	<50	68 ± 4.0	95 ± 6.0
	<4	<50	61 ± 8.0	90 ± 10
21A	-	<70	85 ± 6.0	90 ± 15
21B	-	-	90 ± 10	100 ± 20
22	-	-	52 ± 8.8	103 ± 9.1
23	-	-	69 ± 4.0	98 ± 5.0
24	-	-	83 ± 5.1	100 ± 5.0
	-	-	79 ± 5.0	111 ± 5.1
25	<9	<78	49 ± 11	102 ± 8.4
26	-	28 ± 9.4	74 ± 5.6	98 ± 6.4
27	<9	36 ± 12	72 ± 3.4	104 ± 3.0
28	-	-	57 ± 20	131 ± 18 [a]
29	<4	<33	74 ± 2.0	97 ± 2.0
	<3	38 ± 11	74 ± 2.1	97 ± 2.1
30	<7	<72	74 ± 4.1	104 ± 4.9
	<6	52 ± 13	74 ± 7.2	102 ± 2.4
31	<36	<128	57 ± 15	105 ± 14
32	<3	<40	81 ± 3.5	97 ± 2.7
Lab Ave. $\pm S\overline{X}_j$	<9	38.3 ± 9.7	73.3 ± 9.6	100.0 ± 6.6
Ref. Conc. $\pm Sy_j$	-	29.9 ± 0.5	79.6 ± 2.2	99.5 ± 2.3

[a] Rejected by ASTM test for outliers.

TABLE 5. GAMMA EMITTERS IN WATER, PRECISION SUMMARY FOR SAMPLE 1

Parameter [a]	Co-60	Ru-106	Cs-134	Cs-137
Y_j (pCi/l)	201.9	60.5	161.0	202.8
$\overline{X}_j$ (pCi/l)	201.6	60.9	151.2	202.2
$S\overline{X}_J$ (pCi/l)	9.1	16.6	10.6	12.1
S_{r_J} (pCi/l)	9.9	13.7	10.8	8.0
S_{L_j} (pCi/l)	5.8	13.5	7.4	10.7
S_{R_J} (pCi/l)	11.5	19.2	13.1	13.4
V_{r_j} (%)	4.9	23	7.1	4.0
V_{L_J} (%)	2.9	22	4.9	5.3
V_{R_j} (%)	5.7	32	8.7	6.6
$\overline{V}_{R_j}$ (%)	3.2	21	5.1	3.2
$\overline{V}_{L_j}$ (%)	3.2	22	4.9	5.5
$\overline{V}_{r_j}$ (%)	5.2	29	8.7	6.5
$\overline{S}_{r_j}$ (pCi/l)	6.5	12.8	7.7	6.5
$\overline{S}_{R_j}$ (pCi/l)	10.5	17.7	13.2	13.1
I_{r_j} (pCi/l)	18.4	36	22	18.4
I_{R_j} (pCi/l)	30	50	37	37
Aj (%)	99.9	100.7	93.9	99.7
tj	-0.19	0.09	-5.39	-0.29
t_c (P)	2.80 (34)	2.41 (15)	2.80 (34)	2.80 (34)

[a] Terms defined in text and the List of Abbreviations and Symbols.

TABLE 6. GAMMA EMITTERS IN WATER, PRECISION SUMMARY FOR SAMPLE 2

Parameter [a]	Co-60	Ru-106	Cs-134	Cs-137
Y_j (pCi/l)	98.8	15.4	7.9	393.5
$\bar{X}_j$ (pCi/l)	101.0	28.0	7.8	389.3
$S_{\bar{X}_J}$ (pCi/l)	6.1	12.8	1.0	20.9
S_{r_J} (pCi/l)	3.5	7.5	2.3	7.8
S_{L_j} (pCi/l)	5.6	11.6	0 [b]	20.2
S_{R_J} (pCi/l)	6.6	13.8	2.3	21.7
V_{r_j} (%)	3.5	27	30	2.0
V_{L_J} (%)	5.6	41	0 [b]	5.2
V_{R_j} (%)	6.6	49	30	5.6
$\bar{V}_{r_j}$ (%)	4.4	24	27	2.3
$\bar{V}_{L_j}$ (%)	5.0	25	0 [b]	4.7
$\bar{V}_{R_j}$ (%)	7.4	42	30	5.3
$\bar{S}_{r_j}$ (pCi/l)	4.4	6.7	2.1	9.0
$\bar{S}_{R_j}$ (pCi/l)	7.5	11.8	2.3	21
I_{r_j} (pCi/l)	12.5	19.0	5.9	26
I_{R_j} (pCi/l)	21	33	6.5	59
Aj (%)	102.2	181.8	98.7	98.9
tj	2.07	2.41	-0.40	-1.17
t_c (P)	2.79 (33)	1.82 (6)	2.44 (16)	2.80 (34)

[a] Terms defined in text and the List of Abbreviations and Symbols.
[b] Following the ASTM E691 procedures, the value is set = 0.

TABLE 7. GAMMA EMITTERS IN WATER, PRECISION SUMMARY FOR SAMPLE 3

Parameter [a]	Co-60	Ru-106	Cs-134	Cs-137
Y_j (pCi/l)	9.81	5.9	-	19.9
$\overline{X}_j$ (pCi/l)	11.7	<47	<7	21.5
$S_{\overline{X}_J}$ (pCi/l)	2.5	-	-	2.7
S_{r_J} (pCi/l)	1.43	-	-	2.2
S_{L_j} (pCi/l)	2.3	-	-	2.2
S_{R_J} (pCi/l)	2.7	-	-	3.1
V_{r_j} (%)	12.2	-	-	10.2
V_{L_J} (%)	20	-	-	10.2
V_{R_j} (%)	23	-	-	14.4
$\overline{V}_{r_j}$ (%)	11.6	-	-	10.5
$\overline{V}_{L_j}$ (%)	21	-	-	9.4
$\overline{V}_{R_j}$ (%)	22	-	-	13.6
$\overline{S}_{r_j}$ (pCi/l)	1.36	-	-	2.3
$\overline{S}_{R_j}$ (pCi/l)	2.6	-	-	2.9
I_{r_j} (pCi/l)	3.8	-	-	6.5
I_{R_j} (pCi/l)	7.4	-	-	8.2
Aj (%)	119.3	-	-	108.0
tj	3.63	-	-	3.25
t_c (P)	2.62 (23)	-	-	2.75 (30)

[a] Terms defined in text and the List of Abbreviations and Symbols.

TABLE 8. GAMMA EMITTERS IN WATER, PRECISION SUMMARY FOR SAMPLE 4

Parameter [a]	Co-60	Ru-106	Cs-134	Cs-137
Y_j (pCi/l)	-	29.9	79.6	99.5
$\overline{X}_j$ (pCi/l)	<9	38.3	73.3	99.5
$S\overline{X}_J$ (pCi/l)	-	9.6	9.6	6.4
S_{r_J} (pCi/l)	-	7.2	3.7	4.5
S_{L_j} (pCi/l)	-	8.1	9.2	5.6
S_{R_J} (pCi/l)	-	10.8	9.9	7.2
V_{r_j} (%)	-	19	5.0	4.5
V_{L_J} (%)	-	21	12.6	5.6
V_{R_j} (%)	-	28	13.5	7.2
$\overline{V}_{r_j}$ (%)	-	23	7.7	4.7
$\overline{V}_{L_j}$ (%)	-	23	12.6	6.5
$\overline{V}_{R_j}$ (%)	-	36	13.5	8.2
$\overline{S}_{r_j}$ (pCi/l)	-	8.8	5.6	4.7
$\overline{S}_{R_j}$ (pCi/l)	-	13.8	9.9	8.2
I_{r_j} (pCi/l)	-	25	15.9	13.3
I_{R_j} (pCi/l)	-	39	28	23
Aj (%)	-	128.1	92.1	100.0
tj	-	3.03	-3.83	0.0
t_c (P)	-	2.29 (12)	2.80 (34)	277 (34)

[a] Terms defined in text and the List of Abbreviations and Symbols.

TABLE 9. GAMMA EMITTERS IN WATER, NUCLEAR DATA

Gamma Emitter	Half-Life (years)	Decay Mode	Primary Gamma-Ray Energies (keV) and Percent Abundance
Co-60	5.272	β^+ (93%), EC (7%)	1173.2 (99.9%), 1332.5 (100.0%)
Ru-106	1.008	β^- (100%)	511.8 (20.6%), 621.8 (9.8%)
Cs-134	2.062	β^- (99+%)	563.3 (8.4%), 569.3 (15.4%), 604.7 (97.6%), 795.8 (85.4%), 801.8 (8.7%)
Cs-137	30.17	β^- (100%)	661.6 (84.6%)

TABLE 10. GAMMA EMITTERS IN WATER, CS-134 RESULTS

	Concentrations of Cs-134 pCi/l ± Su		
Sample	All Laboratories	Labs Using Mound or EPA Standards	Labs Using Other Standards
1	151.2 ± 4.4	152.2 ± 11.7 (26 labs)	148.0 ± 4.6 (8 labs)
2	7.8 ± 1.0	7.9 ± 0.9 (13 labs)	7.6 ± 1.5 (3 labs)
4	73.3 ± 9.6	73.2 ± 9.4 (26 labs)	73.6 ± 11.0 (8 labs)

TABLE 11. GAMMA EMITTERS IN WATER, LABORATORY PARAMETERS

Lab	Sample Size (ml)	Counting Time (Min)	Source of Standards [a]	Detector(s)	Gamma Stripping Method
1a	1,000	1,000	Amersham	100 cm^3 Ge(Li)	Canberra code
1b	1,000	1,000	Mound	100 cm^3 Ge(Li)	Hand
2	3,600	1,259-3,777	Mound	17% and 21% Ge(Li)	Hand and computer
3	3,500	100	Mound	65 cm^3 Ge(Li)	Hand
4	4,000	333	Mound	3 cm^3 Ge(Li)	LWAPCA code
5	600	1,000	Mound	117 Cm^3 Ge(Li)	Computer
6	3,500	480	EPA-Las Vegas	120 and 125 cm^3 Ge(Li)	HYPERMET code
7	1,000	1,000	Mound	45 cm^3 Ge(Li)	Hand
8	500	953-1,434	Amersham	12% Ge(Li)	Computer
9	1,000	417	Mound	104 cm^3 Ge(Li)	Nuclear Data code
10	500	1,000	EPA-Las Vegas	75 cm^3 Ge(Li)	Nuclear Data code and hand
11	2,500	1,000	NEN	90 cm^3 Ge(Li)	Canberra Spectran F
12	900	1,400	NBS or Amersham	50 cm^3 Ge(Li)	Hand
13	3,500	1,000	EPA-Las Vegas	4 x 4 NaI(Tl)	Matrix method
14	3,000	1,000	Mound	85 cm^3 Ge(Li)	Nuclear Data code
15	3,000	422-1,083	EPA-Las Vegas	18% and 10% Ge(Li)	Hand and computer
16	3,500	120	Mound	90 cm^3 Ge(Li)	Nuclear Data code
17	3,500	900	Mound	77 cm^3 Ge(Li)	Nuclear Data code
18	500	4,000	Mound	74 cm^3 Ge(Li)	Hand
19	600	900	Mound	112 cm^3 Ge(Li)	Tracor Northern code
20	1,000	975-3,885	EPA-Las Vegas	95 cm^3 Ge(Li)	Computer
21a	3,500	100	EPA-Las Vegas	3 x 3 NaI(Tl)	Matrix analysis
21b	3,500	100	EPA-Las Vegas	55 cm^3 Ge(Li)	Hand
22	3,000	1,500	NBS	15 cm^3 Ge(Li)	Canberra Spectran III
23	1,000	1,000	NEN	150 cm^3 Ge(Li)	Canberra Spectran III
24	3,500	50	Mound	4 x 4 NaI(Tl)	Matrix analysis
25	400	1,000	Mound	84 cm^3 Ge(Li)	Hand
26	600	333	Mound	50 cm^3 Ge(Li)	Tracor Northern code
27	50	333	Amersham	20% Ge(Li)	Nuclear Data code
28	500	1,000	EPA-Las Vegas	25 cm^3 Ge(Li)	Computer
29	500	1,014-4,275	Mound	Ge(Li)	Computer
30	3,000	180-4,000	APT	15% Ge(Li)	Computer
31	500	667	Mound	65 cm^3 Ge(Li)	Hand
32	600	993-3,838	Mound	120 cm^3 Ge(Li)	Computer and hand

[a] NEN - New England Nuclear; NBS - National Bureau of Standards; APT - Applied Physical Technology, Inc.

TABLE 12. GAMMA EMITTERS IN WATER, GAMMA-RAYS MEASURED

Gamma Emitter	E_γ	Laboratories Which Measured Gamma-Ray	Number of Labs
Co-60	1173	3, 4, 5, 8, 9, 10, 12, 14, 19-22, 25-29, 32	18
	1333	1-7, 10, 11, 13-19, 21-24, 26, 28, 30, 31, 32	25
Ru-106	512	3, 9, 13, 21, 23-26	8
	622	1-8, 10, 11, 12, 14, 15, 17-20, 22, 26, 29-32	23
Cs-134	570	5, 14, 26	3
	605	1-4, 6, 9-12, 14, 19-23, 26, 28, 30, 31, 32	19
	796	1, 3, 5, 7, 8, 10, 13-19, 21, 24-29, 32	21
Cs-137	662	1-32	32

TABLE 13. COMPARISON OF RESULTS OF LABORATORIES USING Ge(Li) WITH LABORATORIES USING NaI(Tl) DETECTORS

	Co-60 (pCi/l)	Cs-134 (pCi/l)	Cs-137 (pCi/l)	Ru-106 (pCi/l)
Kv [a]	201.9 ± 3.1	161.0 ± 4.4	202.8 ± 4.7	60.5 ± 1.1
Ge(Li)	201.4 ± 12.0 (31) [b]	149.6 ± 12.7 (31) [b]	203.0 ± 12.1 (31) [b]	62.4 ± 20.1 (13) [b]
NaI(Tl)	198.7 ± 3.2 (3) [b]	158.0 ± 1.7 (3) [b]	196.0 ± 14.0 (3) [b]	62.0 ± 5.7 (2) [b]
Kv [a]	98.8 ± 1.5	79.6 ± 2.2	393.5 ± 9.2	29.9 ± 0.5
Ge(Li)	101.4 ± 6.3 (30) [b]	72.6 ± 8.7 (30) [b]	392.2 ± 22.6 (31) [b]	39.1 ± 9.5 (11) [b]
NaI(Tl)	97.3 ± 3.8 (3) [b]	82.3 ± 2.3 (3) [b]	383.7 ± 13.5 (3) [b]	27.5 ± 10.6 (1) [b]
Kv [a]	9.81 ± 0.15	7.9 ± 0.2	99.5 ± 2.3	15.4 ± 0.3
Ge(Li)	11.4 ± 2.6 (19) [b]	7.4 ± 2.3 (15) [b]	99.9 ± 6.6 (28) [b]	30.9 ± 15.9 (5) [b]
NaI(Tl)	12.2 ± 3.4 (3) [b]	6.3 ± 0.7 (1) [b]	99.3 ± 8.3 (3) [b]	19.0 ± 1.0 (1) [b]
Kv [a]			19.9 ± 0.5	5.9 ± 0.1
Ge(Li)	<9	<7	21.4 ± 3.7 (28) [b]	<45 (22) [b]
NaI(Tl)			21.7 ± 1.2 (3) [b]	<12 (1) [b]

[a] Known value of the reference sample radionuclide concentration.
[b] Number of laboratories from which test results were averaged.

TABLE 14. GAMMA EMITTERS IN WATER, RADIONUCLIDE DETECTION LIMITS

	Lower Limit of Detection (pCi/l)			
Lab	Co-60	Ru-106	Cs-134	Cs-137
9	3.7	21	2.8	2.7
10	4.4	59	4.1	5.8
15	12.3	59	11.4	12.0
16	5.2	19	6.6	5.8
18	2.5	5.1	2.1	2.0
19	3.0	32	3.1	3.6
21	12.5	62	10.6	16.6
28	15.8	-	5.5	5.9
31	10.0	108	10.3	11.4
32	3.3	29	3.0	3.3
Average	7.3	44	8.3	6.9

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APPENDIX A

LABORATORIES PARTICIPATING IN THE GAMMA EMITTERS IN WATER COLLABORATIVE STUDY

Alabama Power Company
Ashford, Alabama

Argonne National Laboratory
Argonne, Illinois

Armed Forces Radiobiology Research Institute
Bethesda, Maryland

California State Department of Health
Berkeley, California

Carolina Power and Light Company
Platteville, Colorado

Eastern Environmental Radiation Facility
Montgomery, Alabama

EPA, EMSL-Cincinnati
Cincinnati, Ohio

Florida Department of Health and Rehabilitative Services
Orlando, Florida

Iowa State University
Ames, Iowa

James A. Fitzpatrick Nuclear Power Plant
Lycoming, New York

Kerr-McGee Technical Center
Oklahoma City, Oklahoma

Los Alamos National Laboratory
Los Alamos, New Mexico

Michigan Department of Public Health
Lansing, Michigan

Mississippi State Board of Health
Jackson, Mississippi

New York State Department of Health
Albany, New York

North Carolina Department of Human Resources
Raleigh, North Carolina

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Oklahoma State Department of Health
Oklahoma City, Oklahoma

Reynolds Electrical and Engineering Company
Las Vegas, Nevada

Sandia National Laboratories
Albuquerque, New Mexico

South Carolina State Department of Health and
Environmental Control
Columbia, South Carolina

Tennessee Division of Occupational and
Radiological Health
Nashville, Tennessee

Tennessee Valley Authority
Vonore, Tennessee

Union Carbide Corporation
Chemical Analysis Section
Oak Ridge, Tennessee

University of Pittsburg
Pittsburg, Pennsylvania

University of Washington
Seattle, Washington

U.S. Air Force, OEHL/RZE
Brooks Air Force Base, Texas

U.S. Department of Energy
Environmental Measurements Laboratory
New York, New York

U.S. Department of Energy
Radiological and Environmental Sciences Laboratory
Idaho Falls, Idaho

Westinghouse Electric Corporation
Wesmoreland County, Pennsylvania

Wisconsin Division of Health
Madison, Wisconsin

Yankee Atomic Electric Company
Westborough, Massachusetts

APPENDIX B

GAMMA EMITTING RADIONUCLIDES IN DRINKING WATER
METHOD 901.1

1. Scope and Application

1.1 This method describes the use of gamma spectroscopy for the measurement of gamma photons emitted from radionuclides without separating them from the sample matrix. This technique makes it possible to ascertain whether a hazardous concentration of a specific gamma emitter is present in a drinking water sample.

1.2 The limits set forth in PL 93-523, 40 FR 34324 recommend that in the case of man-made radionucldies, the limiting concentration is that which will produce an annual dose equivalent to 4 mrem/year. This is calculated on the basis of a 2 liter per day drinking water intake using the 168-hour data listed in NBS Handbook 69. If several radionuclides are present, the sum of their annual dose equivalent must not exceed 4 mrem/year.

1.3 Two types of gamma detectors are currently widely used, namely, the thallium activited sodium iodide crystal NaI(Tl), and the lithium drifted germanium detector, Ge(Li). The Ge(Li) detector does not detect gamma photons as efficiently as the NaI(Tl) detector, but its photon energy resolution is far better than that of the NaI(Tl) detector. Because of its energy resolution advantage and the availability of large active volume Ge(Li) detectors, a Ge(Li) detection system is recommended for measuring gamma emitting radionuclides in drinking water samples.

1.4 The method is applicable for analyzing water samples that contain radionuclides emitting gamma photons with energies ranging from about 60 to 2,000 keV. The required sensitivity of measurement for the more hazardous gamma emitters is listed in the National Interim Drinking Water Regulations, Section 141.25. For a method to be in compliance, the detection limits for photon emitters must be 1/10 of the applicable limit. The detection limits for cesium-134 and cesium-137, which are 10 and 20 pCi/l respectively, are met by this procedure.

2. Summary of Method

2.1 A homogeneous aliquot of drinking water is put into a standard geometry for gamma counting. The counting efficiency for this

geometry must have been determined with standard (known) radionuclide activity. Sample aliquots are counted long enough to meet the required sensitivity of measurement, specified by the NIPDWR (see Appendix C).

2.2 The gamma spectrum is printed out and/or stored in the appropriate computer-compatible device for data processing (calculation of sample radionuclide concentratiions).

3. Sample Handling and Preservation - See Section 3, Method 900.0

4. Interferences

4.1 Significant interference occurs when counting a sample with a NaI(Tl) detector and the sample radionuclides emit gamma photons of nearly identical energies. Such interference is greatly reduced by counting the sample with a Ge(Li) detector.

4.2 Sample homogeneity is important to gamma count reproducibility and counting efficiency validity. When sample radionuclides are adsorbed on the walls of the counting container, the sample is no longer homogeneous. This problem can be lessened by adding 15 ml 1N HNO_3 per liter of sample at collection time.

5. Apparatus - See Appendix D for Details and Specifications

5.1 Large volume (>50 cm^3) Ge(Li) detector or 4" x 4" NaI(Tl) detector.

5.2 Gamma-ray spectrometer plus analyzer with at least 2048 channels for Ge(Li) or 512 for NaI(Tl).

5.3 Standard geometry sample counting containers for either detector. (1-pint cylindrical container or 4-liter Marinelli polyethylene beaker.)

5.4 Access to a computer.

6. Reagents

6.1 Radon free distilled or deionized water for standard preparation and sample dilution.

6.2 Nitric acid, 1N: Mix 6.2 ml of 16N HNO_3 (conc.) with distilled water and dilute to 100 ml.

7. Calibration

7.1 A Ge(Li) detector-gamma spectrometer can be calibrated for energy resolution as follows:

NBS or NBS-traceable standard solutions are prescribed for this calibration. Adjust the analyzer amplifier "gain" and analog-to-digital coverter "zero offset" to locate each photopeak in its appropriate channel. For a Ge(Li) detector system a 0.5 or 1.0 keV per channel calibration is recommended. For a NaI(Tl) detector system a 10 or 20 keV per channel calibration is satisfactory since the energy resolution of this type detector is lower than that of the Ge(Li) detector.

7.2 For NaI(Tl), a library of radionuclide gamma energy spectra is prepared with known radionuclide-water sample concentrations at standard sample geometries; for Ge(Li), a single solution containing a mixture of fission products may be used. These standard solutions are available from NBS or the Quality Assurance Division, EMSL-Las Vegas. Counting efficiencies for the various gamma energies (photopeaks) are determined from the activity counts of those known value samples. A counting efficiency vs. gamma energy curve is determined for each container geometry and for each detector that is to be used for sample analysis. Known amounts of various radionuclides that emit gamma photons with energies well spaced and distributed over the normal range of analysis may also be used for this calibration. These are put into each container geometry and gamma counted for a photopeak spectrum accumulation.

7.3 The detector efficiency, E, at a given photopeak energy for a given geometry is determined by using a known quantity or concentration (for a volume geometry) of a gamma emitting radionuclide, as follows:

$$E = \frac{C}{A \times B}$$

where:

C = net count rate, cpm, (integrated counts in the photopeak above the baseline continuum divided by the counting time in minutes),
A = activity of radionuclide added to the given geometry container (dpm),
B = the gamma-ray abundance of the radionuclide being measured (gammas/disintegration).

8. Procedure

8.1 Measure an aliquot of the drinking water sample in a standard geometry (one that has been calibrated).

8.2 Place the standard geometry container (with the sample aliquot) on a shielded Ge(Li) or NaI(Tl) detector and gamma count for a period of time that will meet the required sensitivity of measurement, specified by he NIPDWR. (The required counting time can be determined by equations given in Appendix C.)

8.3 Print the gamma spectrum and/or store the spectrum on the appropriate computer-compatible device.

8.4 Calculate the radioactivity of the gamma emitters present in the sample.

9. Calculations

These calculations are for determinations using a Ge(Li) detector system. With a NaI(Tl) detector system, similar calculations can be done by a computer using a library of radionuclide spectra and a least-squares (1,2) or matrix analysis program (3).

9.1 The isotopes indicated by the gamma spectrum are determinned as follows:

9.1.1 Identify all photopeak energies.

9.1.2 Integrate the photopeak regions of the spectrum and subtract the area under the base line continuum to determine the true photopeak area.

9.1.3 Isotopes are identified by their appropriate photopeaks, and ratios to each other when more than one gamma photon is emitted by an isotope in the sample.

9.2 Calculate the sample radionuclide concentrations, A, in pCi/l as follows:

$$A = \frac{C}{2.22 \times BEV}$$

where:

C = net count rate, cpm, in the peak area above base line continuum,
B = the gamma-ray abundance of the radionuclide being measured (gammas/disintegration),
E = detector efficiency (counts/gamma) for the particular photopeak energy being considered,
V = volume of sample aliquot analyzed (liters),
2.22 = conversion factor from dpm/pCi.

10. Precision and Accuracy

10.1 Precision and accuracy of this test procedure will be determined by a separate collaborative study. However, a summary of the EMSL-Las Vegas cross-check and performance sample studies (six and two, respectively) for the period of August, 1978, to October, 1979 gives the following information about acceptable performance in the analyses of water samples for gamma emitting radionuclides by gamma

spectroscopy. Some laboratories used Ge(Li) detector/gamma spectrometer systems and others used NaI(Tl) detector/gamma spectrometer systems.

10.2 Six gamma emitting radionuclides were used in those studies, namely, chromium-51, cobalt-60, zinc-65, ruthenium-106, cesium-134, and cesium-137. Samples for the August 1978 and October 1978 cross-check samples and the April 1979 performance samples contained cobalt-60 and cesium-134. The February 1979 cross-check samples contained cobalt-60, zinc-65, cesium-134, and cesium-137. The October 1979 cross-check samples contained chromium-51, cobalt-60, cesium-134, cesium-137. The October 1978 performance samples contained cesium-134 and cesium-137.

10.3 Cesium-134 in seven studies was analyzed by an average of 46 laboratories for a 90.8 ± 11.6% average acceptable performance. Cesium-137 in five studies was analyzed by an average of 48 laboratories for a 87.7 ± 11.7% average acceptable performance. Since the radionuclide concentrations in the samples for all studies were well below the maximum allowable concentrations for drinking water, this non-destructive gamma-emitting procedure to ascertain whether cesium-134 or cesium-137 is present is recommended as an alternate to Method 901.0.

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APPENDIX C

DETERMINATION OF COUNTING TIME FOR REQUIRED SENSITIVITY

This is the information and equations to be used for the determination of required counting times to meet the required sensitivities (detection limits) as given in the National Interim Primary Drinking Water Regulations (NIPDWR) (July 9, 1976) Section 141.25(c), and to be used in the monitoring for radionuclides under the Nuclear Regulatory Commission (NRC) and the Department of Energy (DOE) programs.

Three methods of calculation are provided: The first method is based on the definition of sensitivity in terms of detection limit in the NIPDWR. The second method is based on the lower limit of detection "LLD" as given in HASL-300, part D-08, and is recommended by the NRC and DOE. The second method includes a preselected percent chance of a false positive result for a sample having no activity (α) as well as a preselected percent of confidence of detecting activity ($1-\beta$). In the NIPDWR the $1-\beta$ is given as 0.95 or 95% confidence. An $\alpha = 0.05$ and $1-\beta = 0.95$ have been selected for the second method below. The third method is similar to the second method but based on approximations to the first method.

Method I

From the definition of sensitivity (detection limit) in the NIPDWR, at a precision of ± 100% at the 95% confidence level, the net count rate (N) would be:

$$N = 1.96 \; S_n \qquad \text{Eq. 1}$$

Also, the standard deviation, (S_n) of the net count rate, (N), can be calculated from Equation 1 (Appendix B).

$$S_n = \left[\frac{R_o}{t_1} + \frac{B}{t_2} \right] 1/2 \qquad \text{Eq. 2}$$

where:

R_o = gross count rate = net count rate (N) plus the background count rate (B)

t_1 and t_2 = the counting times for the gross count and background count, respectively.

Equating equations 1 and 2:

$$N = 1.96 \left[\frac{R_o}{t_1} + \frac{B}{t_2}\right]^{1/2} \qquad \text{Eq. 3}$$

This can be further simplified by setting $R_o = N + B$.

When sample radioactivity count rate is near the detector background count rate (as with drinking water and other environmental type samples), then the sample counting time and the detector background counting time should be about equal.

If the sample counting time (t_1) is equal to the background counting time (t_2), and $R_o = N + B$, then equation 3 can be simplified to:

$$N = 1.96 \left[\frac{N + 2B}{t_1}\right]^{1/2} \qquad \text{Eq. 4}$$

Solving for t_1:

$$t_1 = \frac{3.84\ N + 7.68B}{N^2} \qquad \text{Eq. 5}$$

Example 1

Assume a water supply has a total dissolved solids, (TDS) of 80 mg/250 ml (320 mg/l), the counting system has a counting efficiency of 6.00% (0.0600 cpm/dpm) for americium-241 alpha particles emitted from a 2-inch diameter dish containing 80 mg of water solids, and an alpha background of 0.05 cpm. How long must a 80 mg/250 ml aliquot (evaporated) be counted to meet the required 3 pCi/l sensitivity?

For the assumptions given the net counting rate (N) would be:

N = Sensitivity x volume x efficiency x 2.22
N = (3 pCi/l) (0.25 l) (0.06 cpm/dpm) 2.22 dpm/pCi)
N = 0.0999 cpm

Then substituting N = 0.0999 and B = 0.05 into equation 5 gives a required counting time of:

$$t_1 = \frac{3.84\ (0.0999) + 7.68\ (0.05)}{(0.0999)^2} = 77 \text{ min.}$$

Example 2

Assume a water supply has a TDS of 80 mg/100 ml (800 mg/l) and the same counting efficiency and alpha background as above. What counting time will be required for the 3 pCi/l sensitivity?

For the assumptions given the net counting rate (N) would be:

N = (3 pCi/l) (0.1 l) (0.060 cpm/dpm) (2.22 dpm/pCi)
N = 0.040 cpm

Then substituting N = 0.040 and B = 0.05 into equation 5 gives a required counting time of:

$$t_1 = \frac{3.84\ (0.040) + 7.68\ (0.05)}{(0.040)^2} = 336 \text{ min.}$$

Method II

From HASL-300* the LLD may be approximated as $LLD \cong (K_\alpha + K_\beta)S_o$ Eq. 6

where:

K_α = the value for the percentile of the standardized normal variate corresponding to the preselected risk for concluding falsely that activity is present (α),
K_β = the corresponding value for the predetermined degree of confidence for detecting the presence of activity ($1-\beta$), and
S_o = the estimated standard error for the net sample activity.

If the values of α and β are set at the same level and if the gross activity and background activity are close, the following approximation may be made:

$$S_o = (S^2_{gross} + S^2_{bkg})^{1/2} = (2\ S^2_b)^{1/2} = S_b\ (2)^{1/2}$$

$$S_o = 1.414\ S_b \qquad \text{Eq. 7}$$

Then equation 1 becomes

$$LLD = 2K\ S_o = 2\ K\ (1.414 S_b)$$

$$LLD = 2.828K\ S_b \qquad \text{Eq. 8}$$

*Harley, J. H., ed. EML Procedures Manual, HASL-380, Env. Meas. Lab., U.S. DOE, New York, NY (1972).

The values for K for common α's are:

α	$1-\beta$	K	2.828K
0.01	0.99	2.377	6.59
0.02	0.98	2.054	5.81
0.05	0.95	1.645	4.66
0.10	0.90	1.282	3.63
0.16	0.84	1.000	2.83
0.50	0.50	0	0

In the equation $LLD = 2.83K S_b$, S_b = (Bkg count)$^{1/2}$ and the Bkg count = Bkg count rate x counting time (Bt)

$$S_b = (Bt)^{1/2} \qquad \text{Eq. 9}$$

$$LLD = 2.828K \cdot S_b = 2.828\ K \cdot (Bt)^{1/2} \qquad \text{Eq. 10}$$

$$N = \frac{LLD}{t} = \text{Sample net count rate}$$

$$\text{Set } N = LLD = \frac{2.828K}{t} \cdot \frac{(Bt)^{1/2}}{} \text{ and solve for t:} \qquad \text{Eq. 11}$$

$$Nt = 2.828K\ (Bt)^{1/2} \qquad \text{Eq. 12}$$

$$t\ (N^2t - (2.828)^2K^2B) = 0. \qquad \text{Eq. 13}$$

Use the positive root for t:

$$t = \frac{(2.828)^2K^2B}{N^2} \qquad \text{Eq. 14}$$

For α = 0.05 and $1-\beta$ - 0.95, K = 1.645, using equation 9, we get:

$$t = \frac{(4.66)^2\ B}{N^2} = \frac{21.71\ B}{N^2}$$

then using the data for the same examples for Method I, the following results are obtained for Method II:

Example 1

Alpha background (B) = 0.05 cpm

Sample net count rate should be (N) = 0.0999 cpm for a required sensitivity or detection limit of 3 pCi/l.

then: $$t = \frac{21.71\ (0.05)}{(0.0999)^2} = \frac{1.09}{0.01} = 109 \text{ min.}$$

Example 2

Alpha background (B) = 0.05 cpm

Sample net count rate should be (N) = 0.040 cpm

then: $$t = \frac{21.71\ (0.05)}{(0.040)^2} = \frac{1.09}{0.0016} = 678 \text{ min.}$$

Method III

The definition of LLD from HASL-300 uses the approximation that the sample counting time and the background counting time are the same. A second approximation considers that the net count is very small or very close to zero. If these two approximations are also used with the EPA definition, we then would have:

$$LLD = N = 1.96 \sqrt{\frac{2B}{t_B}} = 1.96 \sqrt{2} \sqrt{\frac{B}{t_B}} = 2.77\ S_b$$

$$LLD = N = 2.77\ S_b$$

This definition is the approximation of the EPA definition converted to the HASL-300 form (equation 5)

$LLD = 2.828K \cdot S_b$
If we set $2.77\ S_b = 2.828K\ S_b$
Then $K = 0.98$
This gives $LLD = 2.828 \cdot 0.98\ S_b = 2.77\ S_b$
for $K = 0.98$, this is equivalent to an α of 16% and $1-\beta$ of 84%.
Therefore, the table shows $2.77\ S_b$ values for time, since this is the HASL-300 approximation of the EPA definition.

The table gives values of t for:

$$t = \frac{(2.828)^2\ (0.98)^2\ B}{N^2} = \frac{7.681B}{N^2}$$

Example 1

Alpha background (B) = 0.05 cpm

Sample net count rate should be (N) = 0.0999 cpm for a required sensitivity or detection limit of 3 pCi/l.

then: $$t = \frac{7.681\ (0.05)}{(0.0999)^2} = \frac{0.384}{0.01} = 38.4 \text{ min.}$$

Example 2

Alpha background (B) = 0.05 cpm

Sample net count rate should be (N) = 0.040 cpm

then: $$t = \frac{7.681\ (0.05)}{(0.040)^2} = \frac{0.384}{0.0016} = 240 \text{ min.}$$

The next several tables contain compilations of required counting times for several conditions in order to attain a specified sensitivity. These tables only indicate the required counting times for an arbitrary set of conditions. In a laboratory, for a real set of conditions, when the required counting time becomes excessive (>1,000 min), it is recommended that a new counting system or a larger sample or a combination of both be used.

Required Counting Times for Sensitivity of 1 pCi/liter

Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
0.05	16	100	0.04	412.6	860.6
0.05	16	500	0.18	33.8	34.4
0.05	16	1000	0.36	13.9	8.6
0.05	32	100	0.07	130.2	215.1
0.05	32	500	0.36	13.9	8.6
0.05	32	1000	0.71	6.2	2.2
0.05	48	100	0.11	69.9	95.6
0.05	48	500	0.53	8.6	3.8
0.05	48	1000	1.07	3.9	1.0

Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
0.10	16	100	0.04	717.1	1721.2
0.10	16	500	0.18	46.0	68.8
0.10	16	1000	0.36	16.9	17.2
0.10	32	100	0.07	206.3	430.3
0.10	32	500	0.36	16.9	17.2
0.10	32	1000	0.71	6.9	4.3
0.10	48	100	0.11	103.7	191.2
0.10	48	500	0.53	9.9	7.6
0.10	48	1000	1.07	4.3	1.9

Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
1.00	16	100	0.04	6197.9	17211.8
1.00	16	500	0.18	265.2	688.5
1.00	16	1000	0.36	71.7	172.1
1.00	32	100	0.07	1576.5	4303.0
1.00	32	500	0.36	71.7	172.1
1.00	32	1000	0.71	20.6	43.0
1.00	48	100	0.11	712.7	1912.4
1.00	48	500	0.53	34.3	76.5
1.00	48	1000	1.07	10.4	19.1

Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
10.00	16	100	0.04	61005.3	172118.1
10.00	16	500	0.18	2457.5	6884.7
10.00	16	1000	0.36	619.8	1721.2
10.00	32	100	0.07	15278.4	43029.5
10.00	32	500	0.36	619.8	1721.2
10.00	32	1000	0.71	157.7	430.3
10.00	48	100	0.11	6802.4	19124.2
10.00	48	500	0.53	277.9	765.0
10.00	48	1000	1.07	71.3	191.2

Required Counting Times for Sensitivity of 2 pCi/liter

Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
0.05	16	100	0.07	130.2	215.1
0.05	16	500	0.36	13.9	8.6
0.05	16	1000	0.71	6.2	2.2
0.05	32	100	0.14	46.1	53.8
0.05	32	500	0.71	6.2	2.2
0.05	32	1000	1.42	2.9	0.5
0.05	48	100	0.21	26.5	23.9
0.05	48	500	1.07	3.9	1.0
0.05	48	1000	2.13	1.9	0.2

Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
0.10	16	100	0.07	206.3	430.3
0.10	16	500	0.36	16.9	17.2
0.10	16	1000	0.71	6.9	4.3
0.10	32	100	0.14	65.1	107.6
0.10	32	500	0.71	6.9	4.3
0.10	32	1000	1.42	3.1	1.1
0.10	48	100	0.21	34.9	47.8
0.10	48	500	1.07	4.3	1.9
0.10	48	1000	2.13	2.0	0.5

Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
1.00	16	100	0.07	1576.5	4303.0
1.00	16	500	0.36	71.7	172.1
1.00	16	1000	0.71	20.6	43.0
1.00	32	100	0.14	407.6	1075.7
1.00	32	500	0.71	20.6	43.0
1.00	32	1000	1.42	6.5	10.8
1.00	48	100	0.21	187.2	478.1
1.00	48	500	1.07	10.4	19.1
1.00	48	1000	2.13	3.5	4.8

Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
10.00	16	100	0.07	15278.4	43029.5
10.00	16	500	0.36	619.8	1721.2
10.00	16	1000	0.71	157.7	430.3
10.00	32	100	0.14	3833.1	10757.4
10.00	32	500	0.71	157.7	430.3
10.00	32	1000	1.42	40.8	107.6
10.00	48	100	0.21	1709.6	4781.1
10.00	48	500	1.07	71.3	191.2
10.00	48	1000	2.13	18.7	47.8

Required Counting Times for Sensitivity of 3 pCi/liter

Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
0.05	16	100	0.11	69.9	95.6
0.05	16	500	0.53	8.6	3.8
0.05	16	1000	1.07	3.9	1.0
0.05	32	100	0.21	26.5	23.9
0.05	32	500	1.07	3.9	1.0
0.05	32	1000	2.13	1.9	0.2
0.05	48	100	0.32	15.8	10.6
0.05	48	500	1.60	2.6	0.4
0.05	48	1000	3.20	1.2	0.1

Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
0.10	16	100	0.11	103.7	191.2
0.10	16	500	0.53	9.9	7.6
0.10	16	1000	1.07	4.3	1.9
0.10	32	100	0.21	34.9	47.8
0.10	32	500	1.07	4.3	1.9
0.10	32	1000	2.13	2.0	0.5
0.10	48	100	0.32	19.5	21.2
0.10	48	500	1.60	2.7	0.8
0.10	48	1000	3.20	1.3	0.2

Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
1.00	16	100	0.11	712.7	1912.4
1.00	16	500	0.53	34.3	76.5
1.00	16	1000	1.07	10.4	19.1
1.00	32	100	0.21	187.2	478.1
1.00	32	500	1.07	10.4	19.1
1.00	32	1000	2.13	3.5	4.8
1.00	48	100	0.32	87.2	212.5
1.00	48	500	1.60	5.4	8.5
1.00	48	1000	3.20	2.0	2.1

Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
10.00	16	100	0.11	6802.4	19124.2
10.00	16	500	0.53	277.9	765.0
10.00	16	1000	1.07	71.3	191.2
10.00	32	100	0.21	1709.6	4781.1
10.00	32	500	1.07	71.3	191.2
10.00	32	1000	2.13	18.7	47.8
10.00	48	100	0.32	763.8	2124.9
10.00	48	500	1.60	32.5	85.0
10.00	48	1000	3.20	8.7	21.2

Required Counting Times for Sensitivity of 4 pCi/liter

Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
0.05	16	100	0.14	46.1	53.8
0.05	16	500	0.71	6.2	2.2
0.05	16	1000	1.42	2.9	0.5
0.05	32	100	0.28	18.3	13.4
0.05	32	500	1.42	2.9	0.5
0.05	32	1000	2.84	1.4	0.1
0.05	48	100	0.43	11.1	6.0
0.05	48	500	2.13	1.9	0.2
0.05	48	1000	4.26	0.9	0.1
Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
0.10	16	100	0.14	65.1	107.6
0.10	16	500	0.71	6.9	4.3
0.10	16	1000	1.42	3.1	1.1
0.10	32	100	0.28	23.0	26.9
0.10	32	500	1.42	3.1	1.1
0.10	32	1000	2.84	1.4	0.3
0.10	48	100	0.43	13.2	12.0
0.10	48	500	2.13	2.0	0.5
0.10	48	1000	4.26	0.9	0.1
Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
1.00	16	100	0.14	407.6	1075.7
1.00	16	500	0.71	20.6	43.0
1.00	16	1000	1.42	6.5	10.8
1.00	32	100	0.28	108.7	268.9
1.00	32	500	1.42	6.5	10.8
1.00	32	1000	2.84	2.3	2.7
1.00	48	100	0.43	51.3	119.5
1.00	48	500	2.13	3.5	4.8
1.00	48	1000	4.26	1.3	1.2
Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
10.00	16	100	0.14	3833.1	10757.4
10.00	16	500	0.71	157.7	430.3
10.00	16	1000	1.42	40.8	107.6
10.00	32	100	0.28	965.0	2689.3
10.00	32	500	1.42	40.8	107.6
10.00	32	1000	2.84	10.9	26.9
10.00	48	100	0.43	431.9	1195.3
10.00	48	500	2.13	18.7	47.8
10.00	48	1000	4.26	5.1	12.0

Required Counting Times for Sensitivity of 10 pCi/liter

Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
0.05	16	100	0.36	13.9	8.6
0.05	16	500	1.78	2.3	0.3
0.05	16	1000	3.55	1.1	0.1
0.05	32	100	0.71	6.2	2.2
0.05	32	500	3.55	1.1	0.1
0.05	32	1000	7.10	0.5	0.0
0.05	48	100	1.07	3.9	1.0
0.05	48	500	5.33	0.7	0.0
0.05	48	1000	10.66	0.4	0.0

Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
0.10	16	100	0.36	16.9	17.2
0.10	16	500	1.78	2.4	0.7
0.10	16	1000	3.55	1.1	0.2
0.10	32	100	0.71	6.9	4.3
0.10	32	500	3.55	1.1	0.2
0.10	32	1000	7.10	0.6	0.0
0.10	48	100	1.07	4.3	1.9
0.10	48	500	5.33	0.7	0.1
0.10	48	1000	10.66	0.4	0.0

Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
1.00	16	100	0.36	71.7	172.1
1.00	16	500	1.78	4.6	6.9
1.00	16	1000	3.55	1.7	1.7
1.00	32	100	0.71	20.6	43.0
1.00	32	500	3.55	1.7	1.7
1.00	32	1000	7.10	0.7	0.4
1.00	48	100	1.07	10.4	19.1
1.00	48	500	5.33	1.0	0.8
1.00	48	1000	10.66	0.4	0.2

Bkgd C P M	Counting Eff, %	Sample Size, Ml	Req Net C P M	E P A T, Min	4.66 S T, Min
10.00	16	100	0.36	619.8	1721.2
10.00	16	500	1.78	26.5	68.8
10.00	16	1000	3.55	7.2	17.2
10.00	32	100	0.71	157.7	430.3
10.00	32	500	3.55	7.2	17.2
10.00	32	1000	7.10	2.1	4.3
10.00	48	100	1.07	71.3	191.2
10.00	48	500	5.33	3.4	7.6
10.00	48	1000	10.66	1.0	1.9

APPENDIX D

COMMENTS FROM PARTICIPANTS IN THE COLLABORATIVE STUDY

1. The quoted cesium-134 activity in the standard supplied showed a negative bias of 9%.

2. The sensitivity of 6 pCi/l required for ruthenium-106 is below that which is achievalbe by using a typical sample volume (3.6 l) and counting time.

3. The cesium-134 standard appeared to give results about 10% low relative to the other three standards and previous calibrations, and resulted in a non-smooth efficiency curve. Therefore, the cesium-134 standard results were not used in preparation of the efficiency curve.

4. Because of the lower percent abundance of the ruthenium-106 and the higher background, the minimum count time required to reach the sensitivity needed for ruthenium-106 was 7 days. This seemed unreasonable.

5. The concentration of ruthenium-106 in the standard should have been higher.

6. The calculated counting time to reach a sensitivity of 6 pCi/l for ruthenium-106 was approximately 41 hours.

7. I do not believe that this method will meet the requirements of the regulations which call for a detection level of one tenth of the MCL. In a real life situation when 100 or possibly 200 minute counting times could be tolerated, the detection limits of these radionuclides will not be attainable without some sort of concentration.

APPENDIX E

TABLE E. RESULTS OF LAB USING INDEPENDENT METHOD FOR GAMMA EMITTERS IN WATER

Sample	Radionuclide Concentration [a], pCi/l ± S_u			
	Co-60	Ru-106	Cs-134	Cs-137
1	204 ± 13	0 ± 7	167 ± 11	165 ± 14
	174 ± 12	0 ± 7	130 ± 11	178 ± 14
2	78 ± 10	40 ± 60	8 ± 4	370 ± 18
	91 ± 9	20 ± 40	10 ± 4	373 ± 18
3	10 ± 7	50 ± 60	3 ± 3	0 ± 10
	0 ± 7	120 ± 60	0 ± 4	3 ± 10
4	0 ± 6	30 ± 40	99 ± 8	64 ± 11
	8 ± 7	160 ± 60	81 ± 8	92 ± 11

[a] S_u is the standard deviation reported by the laboratory.

APPENDIX F

TABLE F. DATA ON GAMMA STANDARDS* FOR EPA COLLABORATIVE STUDY (JANUARY, 1981)

Standard† ID	Isotope	Acid Medium	Approximate Volume	Half-Life (Yr)	Specific Activity on 1/1/81	
					(pCi/cm3)	(pCi/g)
Co-1	Co-60	0.12 M HCl	28-30 mL	5.272	99.3	99.3
Ru-1	Ru-106	1.0 M HCl	28-30 mL	1.008	56.01	55.24
Cs-1	Cs-134	0.12 M HCl	28-30 mL	2.062	47.31	47.31
Cs-2	Cs-137	0.12 M HCl	11-12 mL	30.17	164.2	164.2

*Standards were obtained from EMSL, EPA-LV and prepared for this study at Mound Facility, Miamisburg, Ohio on December 12, 1980.

†These standards are contained in glass ampoules. Each glass ampoule has been previously scored at the neck of the ampoule and can be readily broken with a file.

EPA COLLABORATIVE STUDY

GAMMA EMITTERS IN DRINKING WATER
(January 1981)

Sample No.	Count Time (Min)	Gamma Emitter	Gammas Measured (KeV)	Determination #1		Determination #2	
				Counts ± σ	Conc. ± σ (pCi/l)	Counts ± σ	Conc. ± σ (pCi/l)
1		Co-60					
		Ru-106					
		Cs-134					
		Cs-137					
2		Co-60					
		Ru-106					
		Cs-134					
		Cs-137					
3		Co-60					
		Ru-106					
		Cs-134					
		Cs-137					
4		Co-60					
		Ru-106					
		Cs-134					
		Cs-137					

(continued)

EPA COLLABORATIVE STUDY (Continued)

GAMMA EMITTERS IN DRINKING WATER
(January 1981)

Sample No.	Count Time (Min)	Gamma Emitter	Gammas Measured (KeV)	Determination #1		Determination #2	
				Counts ± σ	Conc. ± σ (pCi/l)	Counts ± σ	Conc. ± σ (pCi/l)
Standard		Co-60					
		Ru-106					
		Cs-134					
		Cs-137					
Background		Co-60					
		Ru-106					
		Cs-134					
		Cs-137					

Volume or weight of sample used for analysis was _____.

Volume or weight of standard used for analysis was _____.

Detector used in the present study was _____cm^3 Ge(Li) or _____NaI.

Standards used for calibration of the detector were:

☐ supplied in present study ☐ obtained directly from EMSL, EPA-LV.

Method of analysis of gamma-ray spectra was:

☐ by hand ☐ by computer analysis using _____ code (reference if possible)

☐ other (explain)

Laboratory: _____ Laboratory Contact: _____

State results submitted _____

Send results to Vito R. Casella, Monsanto Research Corporation, Mound Facility, Miamisburg, OH 45342.

PLEASE SEND RESULTS BY MARCH 2, 1981.